



Journal of Toxicology and Environmental Health, Part A: Current Issues

Publication details, including instructions for authors and subscription information:

<http://www.tandfonline.com/loi/uteh20>

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Published online: 28 Jul 2011.

To cite this article: Nancy J. Simcox, Anne Bracker, Gary Ginsberg, Brian Toal, Brian Golembiewski, Tara Kurland & Curtis Hedman (2011) Synthetic Turf Field Investigation in Connecticut, Journal of Toxicology and Environmental Health, Part A: Current Issues, 74:17, 1133-1149, DOI: [10.1080/15287394.2011.586941](https://doi.org/10.1080/15287394.2011.586941)

To link to this article: <http://dx.doi.org/10.1080/15287394.2011.586941>

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SYNTHETIC TURF FIELD INVESTIGATION IN CONNECTICUT

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The primary purpose of this study was to characterize the concentrations of volatile organic compounds (VOC), semivolatile organic compounds (SVOC), rubber-related chemicals such as benzothiazole (BZT) and nitrosamine, and particulate matter (PM₁₀) in air at synthetic turf crumb rubber fields. Both new and older fields were evaluated under conditions of active use. Three types of fields were targeted: four outdoor crumb rubber fields, one indoor facility with crumb rubber turf, and an outdoor natural grass field. Background samples were collected at each field on grass. Personal air sampling was conducted for VOC, BZT, nitrosamines, and other chemicals. Stationary air samples were collected at different heights to assess the vertical profile of release. Air monitoring for PM₁₀ was conducted at one height. Bulk samples of turf grass and crumb rubber were analyzed, and meteorological data were recorded. Results showed that personal concentrations were higher than stationary concentrations and were higher on turf than in background samples for certain VOC. In some cases, personal VOC concentrations from natural grass fields were as high as those on turf. Naphthalene, BZT, and butylated hydroxytoluene (BHT) were detected in greater concentration at the indoor field compared to the outdoor fields. Nitrosamine air levels were below reporting levels. PM₁₀ air concentrations were not different between on-field and upwind locations. All bulk lead (Pb) samples were below the public health target of 400 ppm. More research is needed to better understand air quality at indoor facilities. These field investigation data were incorporated into a separate human health risk assessment.

Synthetic turf crumb rubber fields have been installed or are being proposed in many towns throughout Connecticut, and elsewhere in the United States. In many cases the crumb rubber used for infill is made of styrene butadiene rubber (SBR) that originates from recycled automobile tires. The rubber crumbs are roughly the size of grains of coarse sand and generally are spread 2–3 inches thick over the field surface and packed between

ribbons of green plastic used to simulate grass. Laboratory solvent extraction studies identified a number of chemicals that are released from crumb rubber, including polycyclic aromatic hydrocarbons (PAH), tire-derived semivolatile organic compounds (SVOC) such as benzothiazole (BZT), and volatile organic chemicals (VOC) such as acetone, toluene, and ethylbenzene (California Environmental Protection Agency [CAL EPA] 2007; Li et al. 2010;

Received 20 January 2011; accepted 7 April 2011.

We extend a special appreciation to the towns and schools that participated in this study. We thank Paula Schenck, the University of Connecticut Health Center, for careful review of our reports. This study was funded by the Connecticut Department of Environmental Protection.

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Plesser and Lund 2004). In addition, crumb rubber includes some amount of dusts and small particles, which may be further increased by mechanical abrasion and wear that come with use of the fields (Swedish Chemicals Inspectorate, KEMI 2006; NILU 2006). Health questions continue to arise because exposures and risks from playing on these fields have not been fully characterized (Brown 2007; NILU 2006).

A recent U.S. Environmental Protection Agency (EPA) scoping study demonstrated that consistent environmental air monitoring data for some target analytes can be collected on synthetic turf fields (U.S. EPA 2009). The U.S. EPA found that VOC concentrations on turf fields were less than 1 part per billion volume (ppb_v) and that concentrations were similar to nonturf background areas. One rubber-related VOC, methyl isobutyl ketone (MIBK), was found on turf fields at concentrations less than 0.2 ppb_v but not in background areas. Several investigations conducted at the state or municipal level provided air-monitoring results that generally agree with and extend the U.S. EPA findings. The New York City Department of Health and Mental Hygiene and the New York State Department of Environmental Conservation (NYSDEC) evaluated two fields with air sampling methods that included PAH associated with crumb rubber in volatile or particulate form, and none were reported (New York City Department of Health and Mental Hygiene 2009; NYSDEC 2009). These studies also found that rubber dust was not detected in the respirable range. A more comprehensive exposure assessment study conducted in Norway on indoor synthetic turf fields assessed 234 chemicals in the air, finding 14 VOC ranging in concentration from 10 to 85 µg/m³. On these indoor turf fields, concentrations of BZT, PM₁₀, and PM_{2.5} had ranges of 3.9–31.7 µg/m³, 31–40 µg/m³, and 10–19 µg/m³, respectively (NILU 2006). However, none of these studies documented personal air exposures to targeted analytes during active soccer play on synthetic turf fields, and few analyzed for rubber-derived

compounds such as butylated hydroxytoluene (BHT) or nitrosamines.

The primary purpose of this study was to characterize the concentrations of VOC, SVOC, rubber-related chemicals including BZT and nitrosamine, and particulate matter less than 10 µm (PM₁₀) and its constituents in ambient air at selected crumb rubber fields in Connecticut. The goal was to gather these data under summertime conditions during active field use. Air-monitoring data are needed to characterize exposure patterns of targeted compounds in the breathing zone of child and adult athletes using synthetic turf fields. Data from the Connecticut Agricultural Experiment Station (CAES) laboratory head-space analyses on manufacturers' crumb rubber infill were used to guide aspects of the design of this field investigation (Li et al. 2010). Collaborative relationships were also established with those doing similar research in New Jersey, New York State, New York City, and the U.S. EPA to learn of parallel activities and results as this study proceeded.

More specifically, this exposure characterization had the following objectives: (1) to collect personal and stationary sampler measurements relevant to young children who play on synthetic turf crumb rubber fields; (2) to assess airborne concentrations of the targeted chemicals and particulates on the fields and at appropriate background locations, and (3) to submit these data into a risk assessment conducted by the Connecticut Department of Public Health (CT DPH).

METHODS

Sampling Strategy

Industrial hygienists from the Section of Occupational and Environmental Medicine at the University of Connecticut Health Center (OEM UCHC) conducted the field sampling and managed the analytical components. OEM UCHC subcontracted laboratory analyses to three American Industrial Hygiene Association (AIHA)-accredited laboratories: the Wisconsin Occupational Health Laboratory

(WOHL), the Wisconsin State Laboratory of Hygiene (WSLH), and the ESIS Environmental Health Laboratory (EHL) in Cromwell, CT. WSLH analyzed air samples for VOC, SVOC, and PM₁₀. WOHL analyzed bulk crumb rubber head space for VOC and targeted SVOC such as BZT, and air samples for nitrosamines and targeted SVOC. Additional bulk samples were analyzed for lead (Pb) by EHL.

This study investigated synthetic turf fields during July 2009, targeting three types of sites: outdoor crumb rubber fields, an indoor facility with crumb rubber turf, and an outdoor grass field in a suburban area to serve as a community background location. Sampling goals were to collect air samples on older (>3 yr of age) and new (<2 yr) turf fields during active field use and to collect air samples at an upwind site at each field. Sampling dates were chosen to coordinate several factors: sunny and no-wind days, rental sampling equipment costs/availability, field accessibility due to school summer programs, and staff availability. Although most of the field sampling occurred during July 2009, additional samples were collected at the grass field during October 2010 to obtain personal background data. Table 1 provides the total number of air samples collected at each field.

A special focus of the design included personal air sampling of chemicals reported in previous studies that are associated with rubber (VOC, BZT, nitrosamines). Study team members from the CT DPH, Connecticut Department of Environmental Protection (CT DEP), and OEM-UCHC simulated a soccer game for the collection of the personal airborne chemicals. Active play among three to four players consisted of running and kicking the ball on the turf field, one-on-one soccer drills, and "keep-away" soccer games. Study team members were equipped as later described during these activities for 120 min. One water/food break (5–10 min) was taken by the team members during the play period, with other brief breaks taken as needed to check the sampling equipment. As shown in Table 1, personal measurements for nitrosamine, BZT, and VOC were collected from two players at each field.

The sampling strategy also included the collection of stationary air samples collected at different heights on the turf to assess a vertical profile of release. These air samples were collected in areas on the turf field near active play and in areas away from active play to see whether player movement affects the concentration profile. Because crumb rubber includes some amount of dusts and small particles, PM₁₀ air monitoring was incorporated into the stationary sampling plan (using sampling at a single height only). Bulk samples of turf grass and crumb rubber were also collected, and meteorological data (e.g., air direction, wind speed, and ambient air temperature) were recorded.

Field Recruitment

CT DEP recruited six fields: four outdoor turf fields (fields A–D), one indoor turf field (field K), and one outdoor suburban grass area (field L) (Table 2). Six additional fields were recruited to collect crumb rubber bulk samples only (fields E–J). Fields B, C, and J contained silica sand in the crumb rubber. Fields A, B, and K were located in rural areas and fields C, D, and L were in suburban communities with nearby roads with high traffic volume. Field D was also near an interstate highway. Field K, the indoor turf facility, had four exhaust fans at each end of the building. These fans were not operating during sampling. There was an equipment room located inside the facility, containing small electric motorized carts (these carts were driven out of the facility minutes before the sampling began). In addition, the room had a portable charger, an ice machine, maintenance supplies (e.g., cans of paint), and other gym equipment.

Sampling Methods and Laboratory Analyses

Meteorological Sampling Meteorological conditions for each sampling day were collected by a subcontractor (Air Quality Research and Logistics, LLC) with a Davis Vantage Pro 2 weather. Meteorological parameters collected on a continuous (15-min averaging)

TABLE 1. Targeted Compounds, Analytical Methods, and Total Number Of Air Samples Collected at Each Field

Compounds/methods	Location	n	Fields						Sampling comments
			A	B	C	D	K	L	
VOC									
EPA TO-15	Personal	10	2	2	2	2	2	3	At field A, no data at 6 inches on turf AFAP
	On turf area	10	2	2	2	2	2	0	At field C, pesticide application occurred adjacent to turf field
	Background area	6	1	1	1	1	1	4	Sampling conducted twice at grass field L (in 2009 and 2010)
SVOCs scan	On turf area	6	1	1	1	2	1	0	At fields B, C, and L, no data
EPA TO-13A	Background area	6	1	0	0	2	1	2	at background locations
Targeted SVOC									
NIOSH 2550 (modified)	Personal	10	2	2	2	2	2	0	At field D during 6-h sampling, no data at 6 inches or 3 ft on turf
Benzothiazole	On turf area	23	4	4	4	6	4	0	
2-Mercaptobenzothiazole	Background area	12	2	2	2	2	2	2	
4-tert-Octylphenol	Field blanks	7	1	1	1	2	1	1	
Butylated hydroxyanisole	Field spikes	6	1	2	0	1	2	0	
Butylated hydroxytoluene									
Nitrosamines	Personal	10	2	2	2	2	2	0	None
NIOSH 2522	On turf area	12	2	2	2	4	2	0	
	Background area	11	2	2	2	2	2	1	
	Field blanks	7	1	1	1	2	1	1	
PM ₁₀	On turf area	5	1	1	1	1	1	0	At field A, no data at 3 ft on turf or at background location
CFR Title 40 Part 50	Background area	7	1	1	1	1	1	2	
	Field blanks	6	1	1	1	1	1	1	

TABLE 2. Description of Sampling Fields and Weather Conditions During Sampling Day

Field ID	Surface age (location)	Sampling date	Sampling time of day	Ambient temperature on surface (°F)		Wind speed (mph)
				3 inches	36 inches	
A	2 yr (outdoor)	7/27/09	12:15–2:15 pm	79–89	76–83	0–6
B	2 yr (outdoor)	7/15/09	11:30–1:30 pm	83–89	77–80	4–8
C	5 yr (outdoor)	7/20/09	11:30–1:45 pm	85–88	81–82	1–2
D	2 yr (outdoor)	7/14/09	12:35–2:40 pm	80–88	76–86	1–3
		7/28/09	9:30–3:30 pm		68–87*	2–8
K	3 yr (indoor)	7/22/09	3:50–5:50 pm	77–79	78–80	1–2
L	Grass (outdoor)	7/12/09	11:48–1:48 pm	NA	78–80	1–3
		10/8/10	11:45–1:45 pm	NA	65–72*	1–6

Note. Asterisk indicates temperature not measured directly. Information collected from Weather Underground. NA = not available. Temperature information was not collected 3 inches above the surface.

basis included wind speed, wind direction, and air temperature at different heights (near ground level and 3 ft above the ground). Thermometers were enclosed in naturally aspirated radiation shields (Davis part number 7714). Table 2 provides a summary of the meteorological conditions at each field. On

July 28, 2009, meteorological data were not collected during the 6-h sampling at field D and on October 8, 2010, during additional VOC personal sampling. Temperature and wind direction data were obtained from Weather Underground (www.wunderground.com) for these events.

Bulk Sampling

Crumb rubber bulk sampling VOC method

Crumb rubber bulk samples were collected from 11 different fields in June 2009. Table 2 provides the turf surface age for fields A–D and K. The turf surface ages of the other 6 fields were: E (3 yr), F (9 yr), G (4 yr), H (6 yr), I (1 yr), and J (1 yr). Bulk samples were collected from five locations on each field. At each location, crumb rubber was placed in a precleaned glass jar, which was covered with foil and placed in a brown paper bag for shipment at room temperature to WOHL ($n = 55$). WOHL stored the samples in a refrigerator at 4°C. Bulk samples were analyzed for VOC by WOHL method WG086.2, a method based on OSHA PV2120 for the analysis of VOC in air.

Turf fiber and crumb rubber bulk sampling lead method Composite bulk samples of green artificial turf fibers and composite bulk samples of crumb rubber were collected from five locations on each field at study fields only. The bulk samples were placed in zipped plastic bags. Because Pb was detected in the composite crumb rubber bulk sample from field D, 4 additional crumb rubber composite bulk samples and one additional composite fiber bulk sample were collected from field D. As noted in Table 3, the composite bulk samples were collected from the center of the field and at 4 locations that were either 20 or 40 diagonal paces from the corner of the field. The composite bulk samples were analyzed for environmental Pb by ESIS. The analytical method used by the lab was Modified EPA-SW-846-3050/ICP, Modified OSHA ID 125. The sampling and analytical methods are similar to the methods used by New York City Department of Parks and Recreation during its study of 103 crumb rubber fields (New York City Department of Parks and Recreation 2009).

Air Sampling

Volatile Organic Compounds (VOC)

Personal sampling Personal air samples for VOC were collected using evacuated 1.4-L silica-lined SUMMA Canisters with FSL QT

TABLE 3. Concentrations of Lead ($\mu\text{g/g}$) in Fibers and Crumb Rubber at Study Fields

Field	Fiber concentration ($\mu\text{g/g}$)	Crumb rubber concentration ($\mu\text{g/g}$)
A	<60.1 ^a	<71.4 ^a
B	<59.0 ^a	<68.9 ^a
C	<60.2 ^a	<70.4 ^a
D	<59.0 ^a <76.5 ^a	271 ^a <70.6 ^a <78.5 ^a <72.6 ^b <78.7 ^b
K	<60.8 ^a	<72.1 ^a

Note. Limit of detection: 7.5 $\mu\text{g/sample}$. U.S. Environmental Protection Agency (EPA) lead level for soil in children's play areas: 400 ppm ($\mu\text{g/g}$).

^aComposite bulk sample collected from the center of the field and at four locations that were 20 diagonal paces from the corner of the field.

^bComposite bulk sample collected from the center of the field and at four locations that were 20 diagonal paces from the corner of the field.

MicroValve (Entech Instruments, Carlsbad, CA). Two study team members wore a canister at waist height during the sampling session. Each canister was placed inside a cotton "tool belt" and secured to a coated mesh waist belt with plastic ties. Study team members played on the turf field for 120 min while wearing the SUMMA canisters. At the beginning of each sampling event, staff checked each canister's gauge and confirmed that the pressure was at the level noted in the laboratory standard operating procedure (SOP). Staff confirmed that the pressure gauge had reached "0" at the end of the sampling event. Most of the SUMMA canisters collected air for at least 60 min. However, two of the canisters collected air for less than 25 min (field K). The canisters were sent to the WSLH laboratory (Madison, WI) by overnight mail on the day the samples were collected. All canisters were received by WSLH the next day. All 1.4-L canisters were pressure checked upon return to the laboratory and prior to analysis. No canisters were flagged to indicate problems.

Newly purchased items, such as apron belt, coated mesh belt, and plastic twist ties, were used to hold the sampling equipment in

place during personal sampling. Because several VOC, such as acrolein, were present in personal samples and not in any area samples, a request was made to WOHL to analyze these extra items to determine if they released VOC. In October 2010, additional air sampling was conducted to characterize personal VOC exposures on a grass nonturf field (L). These additional background personal samples were collected to better interpret 2009 data in which personal monitors showed consistently higher results than stationary samplers. Three team members repeated the study protocol as described earlier. Three personal samples (using 1.4-L SUMMA canisters) and three area samples (2 with 6-L SUMMA canisters and 1 with a 1.4-L SUMMA canister) were also collected.

Area sampling Area air samples for VOC were collected using evacuated 6-L silica-lined SUMMA Canisters with Nupro Valve (Entech Instruments, Carlsbad, CA). Canisters were placed at 6 inches and at 3 ft above the turf in an area away from active play of study team members (AFAP) during each sampling session. Another canister was placed upwind of the turf field on grass at 3 ft above the ground. At field L (grass field), the canister was placed at 3 feet. At the beginning of each sampling event staff checked each canister's gauge and confirmed that the pressure was at the level noted in the laboratory SOP. At the end of each sampling event, staff confirmed that the pressure gauge had reached "0." Most samples collected air for at least 60 min. However, one canister collected air for less than 20 min (outdoor background, field K). The canisters were sent to the WSLH (Madison, WI) by overnight mail on the day the samples were collected. All canisters were received by WSLH the next day. In total, 16 samples were collected from the various fields and associated upwind, grass background locations (Table 1). The laboratory confirmed that the canisters' valves were closed and tight upon arrival. One 6-L canister valve was open upon arrival. The sample was not analyzed (field A, 6 inches above the turf).

Sample preparation and analysis All canisters (1.4-L and 6-L) were calibrated with a mass

flow controller to collect air samples for up to 120 min by the WSHL. A modified version of Compendium EPA Method TO-15 by gas chromatography/mass spectroscopy (GC/MS) was used to measure ambient-level concentrations for 60 VOC analytes (US EPA 1999). Total volatile organic compound (TVOC) value is the sum of the all the concentrations that were detectable, and is not an approximate concentration based on toluene response.

Each analytical run included one method blank per batch of samples. If an analyte in the method blank was greater than its limit of detection (LOD), the result for that analyte was flagged to indicate blank contamination. One set of samples contained acetone in the blank sample, and concentrations were corrected (samples collected at field B). Duplicate analysis was performed on one sample per analytical batch and were always within 25% for each compound. Daily quality control checks were performed using a second source standard. Analytes in the quality control/QC check standard were always within 30% of the corresponding calibration standards.

Semivolatile Organic Compounds (SVOC)

An SVOC is any organic compound having a vapor pressure of 1 mm Hg or less at standard conditions (293 K and 760 mm Hg). One hundred and twenty SVOC were monitored: (1) 5 targeted rubber-related SVOC: BTZ, 2-mercaptobenzothiazole, 4-*tert*-octylphenol, butylated hydroxanisole (BHA), and BHT, (2) 22 polycyclic aromatic hydrocarbons (PAH), and (3) 93 miscellaneous SVOC associated with air pollution, such as alkanic acids (sources include road dust) and hopanes/steranes (sources include diesel and gasoline vehicles).

Personal and area sampling of five targeted SVOC Personal samples were collected for five targeted rubber-related SVOC: BTZ, 2-mercaptobenzothiazole, 4-*tert*-octylphenol, BHA, and BHT. Air samples for these compounds were collected using sampling pumps fit with XAD-2 adsorbent media and 37-mm,

2- μ m PTFE prefilters. The pumps were pre- and postcalibrated for approximately 2 L per minute (LPM). The samples were collected for 2 h. At fields A–D and K, the personal samples were collected by placing the pumps at waist height on two study team members involved in active play. In total, 10 personal samples were collected.

In addition, 2 area samples were collected at 6 inches and 3 ft above the ground at the following locations: one at each height on the field near active play (NAP), one on the field away from active play (AFAP), and one at the upwind, grass background location. At field L, an area sample was collected at 3 ft. A field blank was submitted for each field. Field spike samples were also submitted for fields A, B, D (6 h), and K. In total, 58 samples were collected, including 7 field blanks and 6 field spikes.

Sample preparation and analysis All samples were analyzed by WOHL using NIOSH Method 2550 (modified) (NIOSH 1998).

Benzothiazole and 2-mercaptobenzothiazole recoveries were incomplete (below 75%). The field spike recovery for BTZ (vapor phase) was also incomplete (mean recovery = 72%). Therefore, results reported were corrected for incomplete recoveries. 4-*tert*-octylphenol, BHA, and BHT recoveries were also adjusted when spike recoveries observed were below 75%. In cases where background signal was observed in reagent and/or method blanks, the reporting limit was raised to account for this. The reporting limit chosen for each analyte also represents the lowest calibration standard that resulted in acceptable back calculated recovery (within $\pm 25\%$ of theoretical value).

Area sampling of PAH and miscellaneous SVOC PAH and miscellaneous SVOC were collected with polyurethane foam samplers (PS-1, Anderson Instruments, Inc., Smyrna, GA) according to U.S. EPA Method TO-13A (U.S. EPA 1999). Air samples were collected for 2 h at flow rates ranging from 207 to 237 LPM. At one field, additional day of air sampling was conducted for 6 h at flow rates ranging from 209 to 226 LPM. Samplers were placed on the turf near the middle of each field and in

a location upwind and on grass off the turf field (background). All of the samples were collected at a height of approximately 4 ft. The same sampler was used for each designated location (background or on-turf) at all fields. Several extension cords (100–150 ft) were used to supply power to samplers from buildings near the sampling fields. The motor of each sampler was exhausted downwind and away from sampling equipment with a 15-ft flexible duct. Our sampling strategy included a 2-h sampling time because it represents a typical activity period for athletes using turf fields. At one of the fields, an extra day of sampling was conducted for 6 h using U.S. EPA Method TO-13A to increase the sensitivity.

Sampler magnehelic gauges were calibrated for each sampling event using a calibrated critical orifice as a transfer standard. The orifices were connected to a slack tube manometer in the UCHC office in Farmington, CT. Manometer and magnehelic gauge readings were recorded, and flow rates were compared to the WOHL calibrations measurements recorded in the WOHL lab. Measurements were within $\pm 10\%$ of one another. Calibration flow verifications were performed after use to ensure that the calculated magnehelic set point was accurate. Prior to each sampling event, sampling heads and samplers were cleaned with hexane.

Sampling heads were loaded with cylindrical glass PUF (polyurethane foam)/XAD-2 cartridge (PUF plug part number 20038, Supelco, Bellefonte, PA) and filter (Whatman quartz microfiber filters, 102 mm; Piscataway, NJ) in the UCHC office. After loading, each head was placed in a zipped plastic bag, then placed in a travel bag, and transported to the field. In the field, samplers were turned on for 5 min. Leak checks were conducted on site prior to sampling. Sampling heads were placed in the PS-1 samplers and magnehelic gauge measurements were recorded on site at the beginning and end of sampling. Magnehelic gauge measurements were the same at the beginning and end of sampling at all fields. Sampling heads were transported to UCHC on ice. Media was processed out of the sampling heads and placed in

glass jars at UCHC. All samples were shipped to WOHL/WSLH on ice on the same day as sampling.

During 2-h sampling at field D on July 14, 2009, the PS-1 sampler was turned on for approximately 10 min without the valve open (sample 217–background). Site coordinator corrected the problem, checked for air leaks, retightened seals, and rechecked for air leaks. During the 6-h sampling session on July 28 at field D, power was lost for approximately 10 min (sample 221–background). The site coordinator reported the power problem, and facilities corrected it immediately.

In total, 12 field samples were collected. The first set of samples collected from field L (community) broke during shipment to WOHL/WSLH. Shipping procedures were modified to place the glass cartridges in foam and extra wrapping. Unfortunately, glass PUF/XAD cartridges broke during transportation of the media to UCHC and insufficient sampling media was available to collect samples from fields B and C (upwind background location only). It was not possible to reschedule these sampling events to collect more data. Ten field samples were analyzed.

Sample preparation and analysis Samples were prepared and analyzed according to U.S. EPA Method TO-13 by WSLH. If an analyte in the method blank was greater than its reporting limit, the result for that analyte was flagged to indicate blank contamination. Concentrations were corrected for any blank contamination. Extraction of most chemicals was complete ranging from 75 to 125% as specified by the EPA Method TO-13A. Final concentrations were adjusted by extraction recoveries for analytes below 75%. Concentrations with recoveries exceeding 125% are not adjusted. Analytes not detected are reported as nondetectable (ND).

Nitrosamines

Personal and area air samples for nitrosamine were collected using sampling pumps fit with Thermosorb/N tubes. The pumps were pre and post calibrated at approximately 2 LPM. The samples were collected for 2 h.

Personal sampling At fields A–D and K, the personal samples were collected by placing the pumps at waist-height on two study team members involved in active play. In total, 10 personal samples were collected.

Area sampling Two area samples were collected on the fields away from active (AFAP) at 6 inches and 3 ft above the ground, and 2 area samples were collected at the upwind, grass background location at 6 inches and 3 ft above the ground. At field L, 1 area sample was collected at 3 ft. At field D during the 6-h sampling event, 2 on-field area samples (6 inches and 3 ft) were collected. A field blank was collected at each field. In total, 40 samples were collected including 7 field blanks. Upon arrival to WOHL, one field sample had a cracked inlet.

Sample preparation and analysis All samples were analyzed by WOHL using NIOSH 2522 (NIOSH 1994) for the following nitrosamines: *N*-nitrosodimethylamine (NDMA), *N*-nitrosomorpholine (NMOR), *N*-nitrosopyrrolidine (NPYR), *N*-nitroso diethylamine (NDEA), *N*-nitrosopiperidine (NPIP), *N*-nitrosodipropylamine (NDPA), and *N*-nitrosodibutylamine (NDBA).

Particulate Matter (PM₁₀)

Personal sampling No personal samples were collected.

Area sampling Area air samples for particulate matter (PM₁₀) were collected using a Harvard impactor (MS&T area sampler, Air Diagnostics and Engineering, Harrison, ME). Samples were collected onto 37-mm Teflon filters (2 μm) at a flow rate of 20 LPM (pump model SP-280, Air Diagnostics and Engineering, Inc., Harrison, ME; S/N 30637 and 30565) (Marple et al. 1987). Two samples were collected at 3 ft above the ground per field: on turf near the middle of the field and upwind off turf on grass (background). Field blanks were collected and analyzed at every sampled field. Extension cords were connected to electrical outlets in external buildings to provide power to the sampling pumps. The airflow rate was measured with a rotameter (AALBORG, Orangeburg, NY, S/N

227-202-4) before and after sampling with a representative sample medium according to HSPH type impactor SOP protocol (6-26-00, Air Diagnostics and Engineering, Harrison, ME; http://www.airdiagnostics.com/indoor_samp equip.html). Flow rates after sampling were within $\pm 5\%$ of the initial flow rate at each sampling field.

Twelve field samples and six field blanks were collected (two field samples and one blank per field). Filters were shipped to the WOHL laboratory on the same day as sampling, on ice, and frozen upon receipt until weight analysis.

Sample preparation and analysis Samples were weighed according to CFR Title 40 Part 50 before and after sampling to determine PM_{10} concentration (U.S. EPA 1970). Tare (before sampling) and postsampling weights were measured thrice on a Mettler Toledo model MX5 balance (weights to 0.001 mg). These measurements were averaged, and the differences between the average tare and post sampling concentrations were used to calculate PM_{10} concentration as micrograms per cubic meter of air ($\mu\text{g}/\text{m}^3$). Final PM_{10} concentrations for field samples were corrected by field blanks (samples at fields C and K were corrected).

RESULTS

Turf Fiber and Crumb Rubber Bulk Samples for Lead

Table 3 shows that all of the composite turf fiber and crumb rubber samples were below the level the U.S. EPA considers as presenting a "soil-lead hazard" in play areas (400 ppm). This definition, however, applies to residential buildings and to soil rather than other surfaces (U.S. EPA 2001). The current Pb results are also below the 300 ppm target set by the Consumer Product Safety Improvement Act for Pb in products intended to be used by children.

VOC

Table 4 summarizes personal monitoring results for VOC at turf fields A–K and grass

field L. Of 60 VOC, 31 were detected on field. However, many of the VOC found in personal air samples were not present in stationary on-field or upwind area samples (e.g., acrolein). Unfortunately, during the 2009 sampling period, the study design did not include personal monitoring during play on a grass field. Therefore, additional personal and area sampling was conducted on a grass field in 2010 using protocols identical to those used in the initial synthetic turf sampling in 2009. The air concentrations of the 23 VOC detected in personal samples on grass field were generally within the same order of magnitude as the personal air concentrations from play on the synthetic turf fields. For example, benzene concentrations on the grass field L ranged from <0.92 to $1.3 \mu\text{g}/\text{m}^3$ ($n = 3$), whereas on fields A–D and K ($n = 10$), benzene concentrations ranged from <0.32 to $1.56 \mu\text{g}/\text{m}^3$. Personal air concentrations were higher on turf than on grass for 21 VOC including acetone, carbon disulfide, hexane, methylene chloride, methyl isobutyl ketone, xylenes, and toluene.

The personal sampling results indicate that players and/or the sampling equipment may be contributing to the concentrations of VOC detected in the personal samplers. This is further explored in our companion paper (Ginsberg et al. 2011, this issue). Interplayer variability of total VOC air concentrations was notable especially on fields B (28.99 vs. $240.51 \mu\text{g}/\text{m}^3$) and K (292.47 vs. $424.27 \mu\text{g}/\text{m}^3$). The highest personal air concentrations on the turf for most VOCs were found at field K. For example, personal air concentrations for methyl isobutyl ketone were almost 10-fold higher indoors (20.44 – 22.08) than outdoor (<2.04 – 3.39).

The concentrations of VOC detected with stationary on-field area samplers were generally similar to background (upwind) samples, with only a few VOC elevated on the turf. Results in Table 5 are shown as pooled turf or background samples because there were too few samples at any one field to make statistical comparisons. By pooling the data and comparing the range of results between on turf and background samples, it was possible to determine whether any

TABLE 4. Comparison of VOC Personal Air Concentrations ($\mu\text{g}/\text{m}^3$) Across All Fields (Outdoor, Indoor, and Grass)

Volatile organic compound	Outdoor turf A–D, $\mu\text{g}/\text{m}^3$ ($n = 8$)			Indoor turf K, $\mu\text{g}/\text{m}^3$ ($n = 2$)		Grass field L, $\mu\text{g}/\text{m}^3$ ($n = 3$)		
	LOD ^a	Number of detects	Maximum	Number of detects	Maximum	LOD	Number of detects	Maximum
1,2,4-Trimethyl benzene	<0.49	3	2.16	2	2.11	<0.42	1	8.83
1,2-Dichloropropane	<0.49	1	1.14	0	ND ^b	<0.39	0	ND
1,3,5-Trimethyl benzene	<0.49	1	1.37	1	1.18	<0.42	1	4.58
1-Ethyl-4-methyl benzene	<0.49	1	1.86	1	1.37	<0.42	1	7.11
Acetone	<1.19	8	52.17	1	92.48	<0.95	3	40.3
Acrolein	<1.15	4	3.66	2	3.89	<0.92	3	2.97
Benzene	<0.32	3	1.56	2	1.18	<0.27	1	1.3
Bromodichloromethane	<0.66	0	ND	1	0.62	<0.66	0	ND
Bromoform	<1.02	4	13.29	1	34.75	<0.87	0	ND
Carbon disulfide	<0.31	2	0.5	2	0.87	<0.26	0	ND
Chlorobenzene	<0.46	1	0.78	0	ND	<0.39	0	ND
Chloromethane	1.16	8	1.7	2	1.57	<0.17	3	1.23
Cyclohexane	<0.34	3	17.51	2	10.3	<0.29	1	4.81
Dichlorodifluoromethane	2.28	8	2.47	2	3.02	<0.42	3	2.72
Ethyl acetate	<0.36	7	11.87	2	11.87	<0.31	3	8.27
Ethylbenzene	<0.43	1	4.29	2	4.77	<0.37	1	2.14
Halocarbon 11	<0.48	8	1.85	2	2.07	<0.48	0	ND
Heptane	<0.41	4	5.72	2	10.22	<0.35	1	2.13
Hexane	<0.30	7	31.29	2	11.25	<0.30	1	6.96
M/P-Xylene	<0.87	2	10.83	2	12.13	<0.74	1	4.64
Methyl ethyl ketone	<0.23	6	2.94	2	44.15	<0.25	3	7.83
Methyl isobutyl ketone	<2.04	4	3.39	2	22.08	<1.64	0	ND
Methylene chloride	<0.34	2	14.08	2	10.3	<0.29	0	ND
o-Xylene	<0.43	1	3.9	2	4.03	<0.37	1	2.43
Propene	<0.17	7	0.89	2	0.76	<0.15	1	1.46
Styrene	<0.43	1	1.96	2	3.53	<0.36	1	2.51
Tetrachloroethylene	<0.67	1	3.29	2	1.34	<0.57	1	14.48
Tetrahydrofuran	<1.48	1	2.47	2	3.53	<1.18	1	1.58
Toluene	<0.53	8	52.66	2	135.4	<0.45	3	39.12
Trichloroethylene	<0.53	1	23.39	2	2.23	<0.45	1	3.35
Vinyl acetate	<0.35	2	1.23	1	2.95	<0.30	2	1.88

^aLOD = limit of detection. LOD is the same for fields A–D and K.^bND, concentration below LOD.

VOC stand out as being elevated on synthetic turf fields. Analytes that appear elevated on this basis include acetone and cyclohexane. VOC air concentrations on turf fields were not different between 6 inches and 3 ft. While total VOC was considerably higher indoors than outdoors, only a few VOC were elevated indoors compared to background, such as ethylbenzene, xylenes, and methyl isobutyl ketone (Table 5).

Among the outdoor fields (A–D), field C reported the largest number of VOC detected in background. The airborne VOC concentrations reported at field C need to be viewed with caution (Tables 4 and 5). During the first 10 min of sampling at field C, a

pesticide applicator sprayed a mixture (Merit 75 WSP Insecticide, Drive 75 DF Herbicide, and Cross Check Insecticide) to the perimeter of an adjacent grass field with a Perma Green Ride-on Spreader. The study coordinator asked the applicator to stop the application but air sampling had already begun in the background location near the grass field when the application occurred.

SVOC

Tables 6 and 7 and Figures 1 and 2 provide the SVOC air concentrations. Table 6 compares the range of PAH air concentrations on all fields (indoor and outdoor) to the

TABLE 5. Stationary VOC Air Concentrations ($\mu\text{g}/\text{m}^3$) on Turf Fields (at 6 inches and 3 ft) and Background (3 ft)

VOC	Outdoor on turf B–D (6 inches), $n = 3^a$		Outdoor on turf A–D (3 ft), $n = 4$		Indoor turf K (6 in and 3 ft), $n = 2$		Background (3 ft), $n = 8$	
	Range	Number of detects	Range	Number of detects	Range	Number of detects	Range	Number of detects
Acetone	3.93–23.71	3	3.65–12.33	3	17.01–12.33	2	4.01–12.64	8
Carbon disulfide	ND ^b	0	ND	0	0.9–0.9	2	ND–0.62	1
Carbon tetrachloride	ND–0.87	2	ND–0.93	2	ND	0	ND–1.3	5
Chlorobenzene	ND	0	ND	0	ND	0	ND–1.10	1
Chloromethane	1.00–1.19	3	1.06–1.45	4	1.17–1.23	2	ND–1.33	7
Cyclohexane	ND–1.51	1	ND	0	0.82–0.82	2	ND	0
Dichlorodifluoromethane	2.23–2.52	3	2.42–2.82	4	2.77–2.87	2	ND–2.72	8
Ethylbenzene	ND	0	ND	0	1.00–1.04	2	ND–1.21	1
Halocarbon 11	1.4–1.51	3	1.46–1.74	4	1.09–2.02	2	ND–2.46	8
Heptane	ND	0	ND	0	0.98–0.98	2	ND–0.53	1
Hexane	ND–0.87	1	ND–0.49	1	7.38–7.38	2	ND–9.4	6
Methylene chloride	ND	0	ND	0	1.10–1.17	2	ND–1.24	5
Methyl ethyl ketone	1.09–1.62	3	1.12–2.03	4	2.00–2.09	2	1.06–1.83	8
Methyl isobutyl ketone	ND	0	ND	0	35.9–35.9	2	ND	0
<i>m/p</i> -Xylene	ND	0	ND	0	2.17–2.17	2	ND–1.78	1
<i>o</i> -Xylene	ND	0	ND	0	0.87–0.91	2	ND–0.91	1
Toluene	0.71–1.13	3	ND–1.13	2	2.78–2.82	2	ND–4.78	6
1,1,2,2-Tetrachloroethane	ND	0	ND	0	ND	0	ND–1.09	2
1,1,2-Trichlorotrifluoroethane	ND	0	ND–0.76	1	ND	0	ND–1.99	2
1,1,2-Trichloroethane	ND	0	ND	0	ND	0	ND–0.76	1
1,1-Dichloroethane	ND	0	ND	0	ND	0	ND–0.8	1
1,1-Dichloroethene	ND	0	ND	0	ND	0	ND–0.63	1
1,2-Dibromoethane	ND	0	ND	0	ND	0	ND–1.84	1
1,3- Butadiene	ND	0	ND	0	ND	0	ND–0.38	1
1,2-Dichlorobenzene	ND	0	ND	0	ND	0	ND–1.37	1
1,3-Dichlorobenzene	ND	0	ND	0	ND	0	ND–1.13	1
1,4-Dichlorobenzene	ND	0	ND	0	ND	0	ND–1.37	1
1,2,4-Trichlorobenzene	ND	0	ND	0	ND	0	ND–0.89	1
1,2-Dichloroethane	ND	0	ND	0	ND	0	ND–0.68	1
1,2-Dichloropropane	ND	0	ND	0	ND	0	ND–0.69	1
Acrolein	ND	0	ND	0	ND	0	ND	0
Benzene	ND	0	ND	0	ND	0	ND–0.92	2
Bromoform	ND	0	ND	0	ND	0	ND–1.74	2
Bromomethane	ND	0	ND	0	ND	0	ND–0.69	1
Chloroethane	ND	0	ND	0	ND	0	ND–0.55	1
Chloroform	ND	0	ND	0	ND	0	ND–0.68	1
<i>cis</i> -1,3-Dichloropropene	ND	0	ND	0	ND	0	ND–0.99	1
Ethyl acetate	ND	0	ND	0	ND	0	ND–0.61	1
Propene	ND	0	ND	0	ND	0	ND–0.48	1
Styrene	ND	0	ND	0	ND	0	ND–0.94	1
Tetrachloroethylene	ND	0	ND	0	ND	0	ND–1.27	2
Vinyl acetate	ND	0	ND	0	ND	0	ND–1.02	1

^aSamples were collected at 3 ft only at field A.^bND = concentration below LOD.

background air concentrations. PAH were generally found at low concentrations ($<1 \text{ ng}/\text{m}^3$) and a few were found outdoors at higher air concentrations than background, such as benzo[a]pyrene. At the indoor field (field K), several PAH were 10-fold higher on turf than

background, including 1-methylnaphthalene, 2-methylnaphthalene, fluorene, naphthalene, and pyrene. Five additional PAH were found indoors only, namely, acenaphthene, acenaphthylene, fluorene, naphthalene, and 2,6-dimethylnaphthalene. Of all the PAH, the air

TABLE 6. Range Concentrations of PAHs (ng/m³) On Outdoor Turf and Upwind Background Locations

PAH	Outdoor on turf, range, ng/m ³ ng/m ³ (n = 5 ^b)	Indoor on turf, concentration, ng/m ³ (n = 1)	Background range, ng/m ³ (n = 4)
1-Methylnaphthalene	3.72–9.31	^a ND	4.08–6.91
2,6 Dimethylnaphthalene	ND–7.65	28.70	ND–10.37
2-Methylnaphthalene	1.88–4.24	63.38	ND–3.31
Acenaphthene	2.14–3.45	17.37	ND–0.3.99
Acenaphthylene	ND–6.59	6.78	ND–0.77
Anthracene	ND–ND	ND	ND–0.02
Benz[a]anthracene	ND–ND	ND	ND–0.03
Benzo[a]pyrene	ND–0.19	ND	ND–0.05
Benzo[b]fluoranthene	ND–0.21	ND	ND–0.07
Benzo[e]pyrene	ND–0.26	ND	ND–0.06
Benzo[ghi]fluoranthene	ND–0.08	ND	ND–ND
Benzo[ghi]perylene	ND–0.14	ND	ND–0.06
Benzo[k]fluoranthene	ND–0.08	ND	ND–0.04
Chrysene	ND–0.34	ND	ND–0.04
Fluoranthene	1.68–6.76	5.55	0.58–3.96
Fluorene	2.21–4.09	53.70	2.43–3.59
Indeno[1,2,3-cd]pyrene	ND–0.05	8.90	ND–0.05
Naphthalene	5.99–14.57	113.00	4.50–16.94
Phenanthrene	5.07–14.34	32.26	6.11–13.05
Pyrene	0.97–6.92	11.84	0.37–3.16

^aND = nondetectable: concentration is less than reporting limits.

^bFour fields were sampled, and one field (D) was sampled twice.

concentration of naphthalene, 113ng/m³, was the highest concentration found.

Table 7 provides the range of air concentrations for miscellaneous SVOC that have higher on turf air concentrations than background. For outdoor fields, air concentrations on turf were greater than background for only 14 miscellaneous SVOC. As with other analytes, a larger number of miscellaneous SVOC were found indoors than outdoors; however, concentrations are within the same order of magnitude as the background air concentrations for most SVOC.

For both PAH and miscellaneous SVOC, the air sampling strategy involved 2-h sampling using stationary monitors. One field was sampled for both 2 and 6 h to determine whether the longer sampling time would increase sensitivity and detect more analytes. A similar array of analytes was detected at both time frames, suggesting that the 2-h sampling time was sufficient. The 2- and 6-h sampling results indicated that numerous SVOC were not detected on the field or in the background location (data not shown).

Of the five targeted SVOC in air, BZT and BHT were the only chemicals detected above background (Figure 1). Concentrations of BZT were higher on the turf at 6 inches away from active play than in background locations at all fields. Most concentrations of BZT and BHT were an order of magnitude lower among the outdoor turf fields than for the indoor field, ranging outdoors at <80–1200 ng/m³ and <80–130 ng/m³, respectively. Indoor concentrations of BZT and BHT on the turf had ranges of 11,000–14,000 and 1240–3900 ng/m³, respectively (Figure 2). 4-*Tert*-octylphenol was found in two air samples but the concentration on turf level was less than background in these cases.

Nitrosamines

All concentrations were below the reporting limits (limits ranging from <0.14 to <0.43).

Particulate Matter PM₁₀

PM₁₀ concentrations were generally greater in background locations (<0.38–17.79)

TABLE 7. On Turf Air Concentrations (ng/m³) of Miscellaneous SVOCs That Are Higher Than Background

SVOC	Outdoor on turf, range, ng/m ³ (n = 5 ^a)	Indoor on turf, ng/m ³ (n = 1)	Background range, ng/m ³ (n = 4)
17A(H)-21B(H)-Hopane	NA ^b	2.21	0.27–2.33
17A(H)-22,29,30-Trisnorhopane	NA	1.56	0.09–0.85
17B(H)-21A(H)-30-Norhopane	NA	2.80	0.29–1.82
22R-Homohopane	NA	0.39	0.11–1.14
22R-Trishomohopane	ND ^c –0.03	0.08	ND–ND
22R-Bishomohopane	ND–0.09	NA	ND–0.09
22S-Bishomohopane	ND–0.11	0.21	0.19–1.56
22S-Homohopane	NA	0.57	2.16–3.31
22S-Trishomohopane	NA	0.13	ND–0.07
Decanoic acid	NA	130.41	35.29–116.96
Docosane	4.25–19.17	NA	0.19–18.26
Docosanoic acid	NA	8.36	1.26–2.82
Dodecane	ND–70.39	236.44	ND–50.45
Dotriacontane	ND–3.78	10.99	ND–3.26
Eicosane	6.18–22.05	67.88	7.85–40.89
Eicosanoic acid	ND–8.43	6.74	ND–1.24
Heneicosane	7.96–24.51	70.67	8.38–18.81
Hentriacontane	ND–8.33	NA	0.39–9.72
Heptacosane	NA	31.46	ND–2.38
Heptadecane	7.28–106.02	367.05	24.24–130.03
Heptadecanoic acid	NA	13.87	2.47–5.70
Heptadecylcyclohexane	NA	ND	ND–0.82
Hexacosane	NA	34.83	ND–1.93
Hexacosanoic acid	NA	1.89	0.70–8.47
Hexadecane	0.77–141.89	526.94	34.09–188.30
Hexadecanoic acid	NA	291.69	36.80–131.48
Hexatriacontane	NA	ND	ND–0.76
Linoleic acid	ND–15.96	NA	ND–0.65
Nonacosane	0.38–6.22	14.55	2.51–6.20
Nonadecane	7.25–43.96	120.22	20.53–83.58
Norpristane	4.94–31.72	170.57	8.23–33.84
Octacosane	ND–7.70	16.48	ND–5.94
Octadecane	1.00–71.82	189.16	18.40–100.51
Octadecanoic acid	8.89–383.47	162.30	9.62–119.38
Octanoic acid	10.12–58.94	352.74	6.58–89.30
Palmitoleic acid	ND–7.40	NA	ND–0.73
Pentacosane	NA	49.65	ND–3.70
Pentacosanoic acid	NA	0.82	0.34–1.16
Pentadecane	NA	580.78	31.68–105.24
Pentadecanoic acid	NA	26.89	7.77–15.86
Pentadecylcyclohexane	NA	ND	0.52–2.52
Pentatriacontane	NA	11.18	ND–1.40
Phytane	NA	33.34	1.51–7.28
Pristane	ND–11.22	48.96	4.03–13.62
Tetracosane	NA	41.21	ND–6.38
Tetracosanoic acid	NA	3.87	1.23–5.54
Tetradecane	NA	481.85	29.69–50.07
Tetradecanoic acid	NA	121.76	19.69–54.59
Tetratriacontane	ND–14.34	11.09	ND–1.80
Triaccontane	NA	11.84	ND–6.61
Triaccontanoic acid	2.47–5.13	2.29	2.00–5.81
Tricosane	0.39–16.16	39.18	2.11–12.47
Tricosanoic acid	NA	2.39	0.35–2.62
Tridecane	NA	211.25	ND–38.33
Tritriacontane	ND–7.02	12.87	ND–2.97
Undecane	NA	361.34	ND–65.42

^aFour fields were sampled, and one field (D) was sampled twice.^bNA = not applicable; concentrations on fields were not greater than background.^cND = nondetectable; concentration below method limit of detection (LOD).

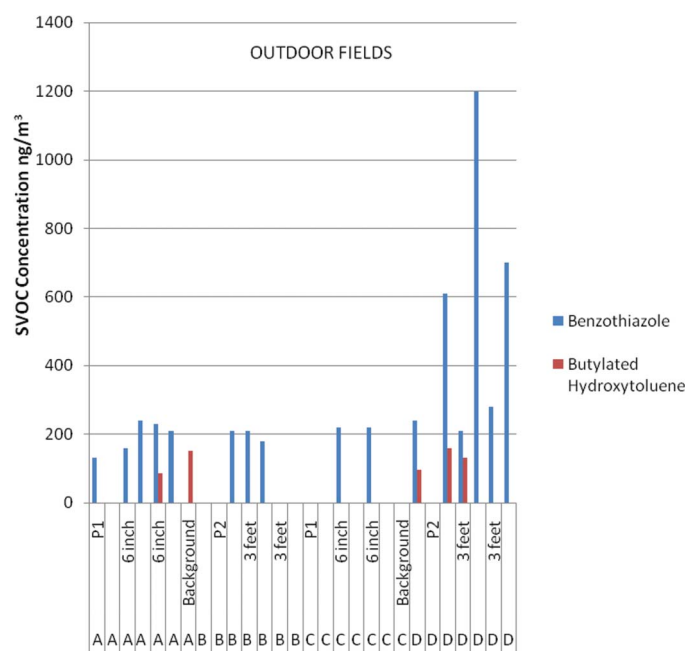


FIGURE 1. Benzothiazole and BHT personal and area air concentrations in fields A–D (color figure available online).

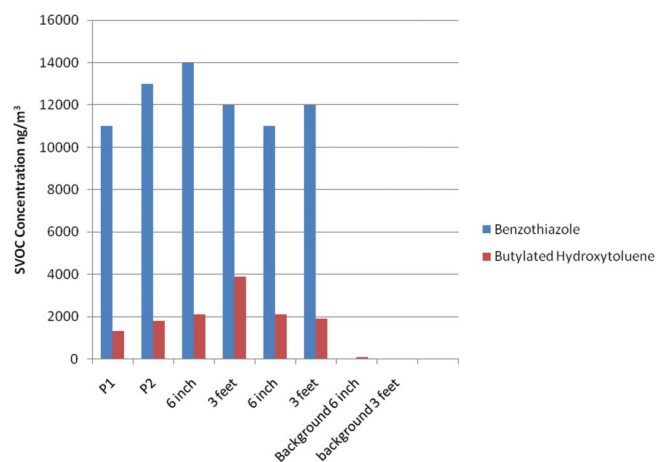


FIGURE 2. Benzothiazole and BHT personal and area air concentrations in field K (color figure available online).

than on the turf (4.52–16.54). In one case the concentration on turf (field B, $5.89 \mu\text{g}/\text{m}^3$) was within the range of background concentrations (4.96 – $17.79 \mu\text{g}/\text{m}^3$). There were no cases either outdoors or indoors where the PM_{10} result was greater on turf than in the background samples. The protocol for sampling at field A was not followed properly, and therefore those data are not available. Following gravimetric analysis, samples were stored at

room temperature until particulate characterization analyses. Six samples were selected for microscopic particle identification and characterization by polarized light microscopy (WP001.20 Analysis), scanning electron microscopy, and energy-dispersive x-ray (EDXA) analyses. These samples were collected from fields B, D, K (on turf), and L (suburban grass). Other samples were not analyzed as planned because rubber fragments were not

easily detected and identification of particles was inconclusive.

DISCUSSION

This is the first study to document personal exposures to VOC, nitrosamines, BZT, and other crumb rubber-related compounds while actively playing on synthetic turf fields. There are no data in the literature on personal air exposures to analytes on synthetic turf fields with which to compare our findings. In general, our area sample results are comparable to the findings of other studies. The combination of using environmental and occupational (U.S. EPA and NIOSH) methods for a 2-h sampling period was sufficient to characterize personal and area exposures associated with active play on synthetic turf fields.

The primary objective of this study was to characterize human exposure via inhalation, and therefore other routes of exposures, such as ingestion and contact, were not included within the scope of the study. This study identified and measured chemicals across several synthetic turf crumb rubber fields and background locations. Measurements collected from background locations and the nonturf grass fields are necessary to better understand the data because many of these chemicals are present in ambient air as a result of air pollution. In addition, personal exposures to some VOC appear to be influenced by the sampling equipment and/or players. The pattern of exposure as shown with BZT concentrations in Figures 1 and 2 is what one would expect from a synthetic turf-related compound. However, our results demonstrate that some VOC did not follow this pattern and so were less certain to be field-related. Higher PAH concentrations of naphthalene, 2-methylnaphthalene, and fluorene were found indoors than outdoors. In one indoor turf field study, NILU (2006) reported similar findings as to the types of PAH (naphthalene, acenaphthylene, and 2-methylnaphthalene) and the range of PAH concentrations (e.g., naphthalene ranged from 11.1 to 56.4 ng/m³).

There are several limitations to this study. This project has a potential for selection bias because participation on the part of field managers was voluntary and self-selected. The sample size was small (four outdoor fields and one indoor field); however, goals of the project were met in recruiting a variety of differently aged outdoor fields, an indoor facility, and a suburban grass field to serve as a community background location. Data presented in this field investigation were deemed suitable for incorporation into a human health risk assessment, which was conducted by the Connecticut Department of Public Health in the risk assessment portion of the project (Ginsberg et al. 2011, this issue).

During the summer of 2009, temperature conditions for the sampling events were on average lower than normal. The 30-yr monthly average maximum temperature for the month of July is 84.9°F, and during July 2009, the average was 79.9°F. Most notably, on sampling days winds were low and sunny conditions prevailed. The temperature for the air sampling conducted in October 2010 was also lower, ranging from 65 to 72°F. This temperature was considered appropriate to meet study goals of examining what may emit from players and their equipment.

Personal sampling occurred at waist height, and not in the normal breathing zone of the players. The placement of sampling devices at this height is not a conventional industrial hygiene personal sampling method but was chosen to better represent a child's height. Some VOC (e.g., acrolein) were found in personal samples and not on the turf or in the background areas. Players wore the SUMMA units close to their bodies, and they were up against the sampling belts and plastic ties that players wore to hold all the sampling equipment. Some preliminary results of belts and ties found that some VOC were emitted from plastic ties and belts worn by players during sampling (data not shown). However, these results do not explain all the elevated personal concentrations found in this study. SUMMA units are a sensitive air-sampling method, and may have also collected VOC associated with

personal care products worn by the team players. Players were asked not to wear products to limit any contamination. Because of the sun exposure, some players wore sun protection and all players sweated. Data from on-grass personal VOC air sampling in October 2010 supports this conclusion in documenting a wide array of VOCs detected from the air samplers worn by players on a grass field that were not detected in the stationary samples (Tables 4 and 5). There are many factors to consider for "control" team members, including the type of player clothing, personal product use, personal characteristics (sweat and exhaled breath), laundering practices, and even food consumed. This is further discussed in the risk assessment portion of the project (Ginsberg et al. 2011, this issue).

Certain events during the course of this investigation affected our ability to take measurements, but this affected only a small number of samples. For example, background samples were not collected at two fields with the PS-1 samplers as a result of media breakage during transportation. In addition, one of the fields (C) was contaminated by a pesticide application, which may explain the larger number of VOC found in comparison to other outdoor fields.

The laboratory was not able to identify rubber particles on the Teflon filters from several fields, and therefore SEM analysis was not completed for all field samples. The U.S. EPA study used polycarbonate filters with the same air sampling method and reported similar difficulties. More research is needed to better characterize PM₁₀ containing crumb-rubber.

The airborne concentrations of VOC, PAH, and targeted SVOC (e.g., BZT) were highest in the indoor field. These data were collected from only one indoor facility. However, BZT air concentrations ranging from 1.1 to 14 µg/m³ in this study were within the same order of magnitude as those reported on Norwegian indoor turf fields (3.9–31.7 µg/m³). The crumb rubber of the indoor facility was manufactured by the same company as field B and was installed 1 yr earlier. The air in the indoor field was not influenced by outdoor factors that may

degrade and offgas chemicals, such as sunlight, high temperatures, rain, and other weather conditions. Some potential point sources were identified in the facility (electric carts, portable chargers, and maintenance supplies); however, these sources most likely contributed minimally to the overall concentrations detected. Most importantly the indoor facility did not have its exhaust system operating on the day samples were collected. More research is needed to better understand chemical exposures in indoor facilities.

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